Three-dimensional Atom Probe Studies of Thin Film Oxide Heterostructures

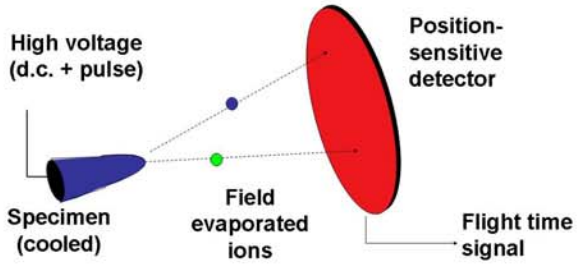
A K Petford-Long[a], C K Sudbrack[a], D Schreiber[a,b], D N Seidman[b] and D J Larson[c]
[a] Materials Science Division, Argonne National Laboratory
[b] Materials Science Department, Northwestern University
[c] Imago Scientific Instruments

(1) Motivation

The nature of the interfaces controls the properties of thin film oxide heterostructures. However these can be difficult to visualize post-deposition, making correlation with properties difficult.

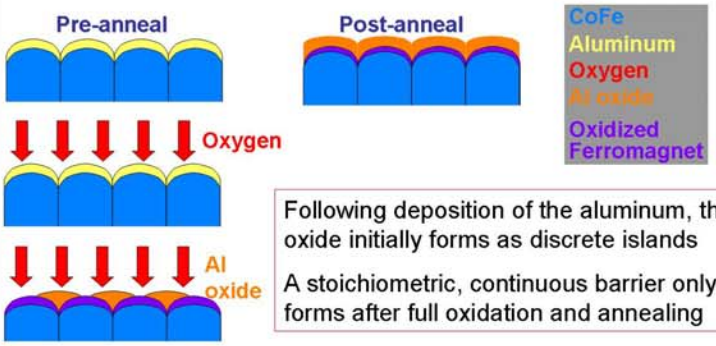
We are using three-dimensional atom probe analysis to address this issue. The atom probe provides three-dimensional atomic-scale information about local chemistry and morphology.

- Single atoms removed and identified
- High magnification gives 3-D atomic-scale map



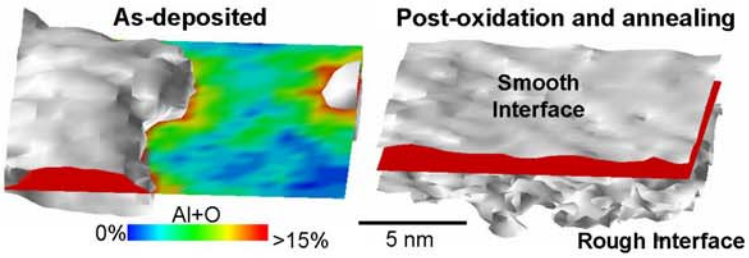
(2) Major Accomplishments

Atom probe analysis of the alumina tunnel barrier in simple magnetic tunnel junctions (MTJs) [Ref 1]:



Following deposition of the aluminum, the oxide initially forms as discrete islands

A stoichiometric, continuous barrier only forms after full oxidation and annealing



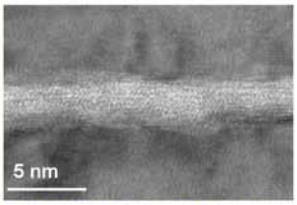
For as-deposited barriers, pinholes between the ferromagnetic layers exist, but the MTJs still display electron tunnelling and a tunnel magnetoresistance.

This work was performed in collaboration with University of Oxford and Seagate Technologies.

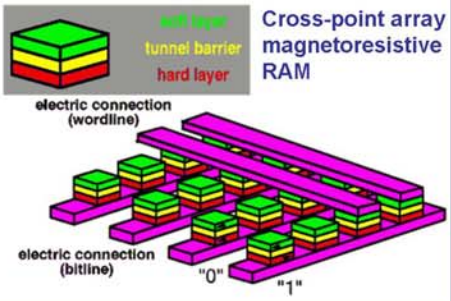
(3) Impact

The atomic-scale resolution of the atom probe data, and the volume of material analyzed ($100 \times 100 \times 100\ nm^3$) provides a means to:

- **Correlate physical properties such as tunneling with interfacial mixing and roughness**
- **Generate realistic models of materials properties such as tunneling characteristics**



Cross-section TEM image of tunnel junction



(4) Future Directions

We will focus on novel systems for which an understanding of local interface chemistry and morphology at the atomic-scale is critical:

- **High TMR tunnel junctions with MgO barriers**
- **All-oxide tunnel junctions with half-metallic ferromagnets for high spin-polarization**
- **Spin-injection structures**
- **Ferroelectric capacitors and nanostructures**
- **Gate oxide structures**

These are non-trivial systems for atom probe analysis and further goals of our research are:

- **Optimization of specimen fabrication from films deposited on arrays of microtips**
- **Refining methods of interface analysis for quantification of roughness and interdiffusion**
- **Use of laser pulsed atom probe for analysis of all-oxide structures**

SEM Image of Microtip Array

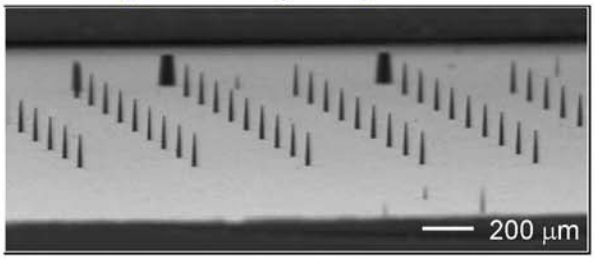


Image courtesy of Imago Scientific Instruments

These investigations will make use of the LEAP instrument at Northwestern University.

[1] A K Petford-Long, Y Q Ma, A Cerezo, D J Larson, E W Singleton and B W Karr, J. Appl. Phys. 98, 124904 (2005)

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